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Environmental Impact of Cremation in Tlalmanalco, State of Mexico

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Abstract: The environmental impact of combustion gas emissions during the cremation process in the municipality of Tlalmanalco, State of Mexico, was investigated. A TESTO 340 combustion analyzer was used over nine days to evaluate 30 cremation services. The average emission values obtained were 84.03 g/h for NO_2, 7,050.9 g/h for SO_2, and 46,194. 4 g/h for CO. Using this data, the dispersion of these pollutants was analyzed with HYSPLIT software and compared with air quality standards. Results showed that the gases dispersed effectively in the air within 1 h, ensuring no risk to the population. However, CO emissions exceeded the limit set by the NADF-017-AIRE-2017 standard for fixed sources, while NO_2 emissions remained below the permissible limit.

Keywords: Pollution air, combustion gas emissions, air quality standards.

1. Introduction

Air pollution is one of the greatest environmental risks to public health. The WHO (World Health Organization) estimated that ambient air pollution caused 4.2 million deaths worldwide in 2019. Of these, 37% were attributed to ischemic heart disease and stroke, 18% to obstructive lung disease, 23% to acute respiratory infections, and 11% to respiratory tract cancer [1].

As a result of the SARS-CoV-2 pandemic in 2020, the number of deaths in Mexico increased to 334,346 [2], consequently raising the number of cremations. To address this demand, a crematorium was installed in the Jardines de Santa Cruz Memorial Pantheon in the Municipality of Tlalmanalco, located east of the State of Mexico. This installation, however, raises environmental concerns due to the emission of polluting gases, such as NO_x (Nitrogen Oxides), SO_x (Sulfur Oxides), CO (Carbon Monoxide), and CO_2 (Carbon Dioxide) [3], all of which contribute to air quality deterioration.

NO_x include two toxic gases, NO (Nitrogen Monoxide) and NO_2 (Nitrogen Dioxide), which, when combined with water, form nitric acid, a key precursor of acid rain. These compounds can also react with other substances through photochemical processes, forming PAN (Peroxyacetyl Nitrate) and contributing to photochemical smog. In humans, NO_x exposure is linked to chronic lung diseases [4].

CO is a major atmospheric pollutant that contributes to the formation of greenhouse gases like CO_2 and O_3. Its effects on human health include reduced oxygen transport to organs and tissues, as well as cardiovascular and neuropsychological impairments [5].

SO_2 (Sulfur Dioxide), the most common SO_x, forms H_2SO_4 (Sulfuric Acid) when combined with water, which can damage ecosystems by harming plants and animals and acidifying surface waters. In humans, SO_2 exposure can cause asthma and bronchitis [6].

The NADF-017-AIRE-2017 standard establishes guidelines to limit air pollutants from cremation processes to protect public health. It specifies maximum permissible emissions for suspended particles, CO, and NO_x during cremation. The hourly average emission limits are 40 mg/m^3 for suspended particles, 120 mg/m^3 for CO, and 180 mg/m^3 for NO_x, all measured under standard

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conditions of 25 ℃, 1 atmosphere, and 11% oxygen [7].

Quantifying the emissions from cremation activities in Tlalmanalco provides insight into their impact on air quality. Comparing these emissions with data from the RAMA (Automatic Atmospheric Monitoring Network) for 2019-2020 enables an assessment of their environmental and health implications using dispersion modeling.

2. Experimental Methodology

The TECMAR 200 crematorium is located on the Mexico-Cuautla federal highway. It uses Liquefied Petroleum Gas (LPG) as fuel and performs an average of five cremation services per day, each lasting approximately 2 h. The crematorium is equipped with North America-brand burners, and its combustion chambers are constructed from brick, concrete, and refractory mortar capable of withstanding temperatures up to 1,600 ℃. The chimney is 6 m high and 0.635 m in diameter, with two sampling ports. Each cremation consumes 12.8685 kWh of electricity and 0.1155 m^3 of LP gas.

Combustion gas analysis was conducted using an electrochemical cell method. This involved extracting flue gases into a portable analyzer, which provided specific and quantitative measurements of the substances circulating through the duct.

3. Experimental Results

Measurements were conducted using a TESTO 340 combustion analyzer for 30 cremation services over nine days between July and August 2022. The gas concentrations are presented in Table 1.

To determine whether the obtained data complied with the NADF-017-AIRE-2017 standard, the gas concentrations in parts per million (ppm) were converted to milligrams of gas per cubic meter of air (mg/m^3) (Table 1). Fig. 1 illustrates the NO_x measurements in mg/m^3, with the maximum permissible value indicated by a red line.

The measured NO_x values are well below the permissible limit and do not pose a risk to the population. Fig. 2 displays the CO measurements in mg/m^3, with the maximum allowable value indicated by a red line.

Table 1 Results of combustion gas measurements from the cremation process.

Number	%	Concentration (ppm)			Concentration (mg gas/m^3 air)		
	O_2	CO	NO_x	SO_2	CO	NO_x	SO_2
1	13.6	4,083	1	32	4,685.409	1.229	83.934
	20.75	1,839	7.1	154	2,110.327	8.729	403.934
2	20.64	28	2	42	32.131	2.459	110.164
	16.74	2,188	3	140	2,510.819	3.688	367.213
3	20	11	29	68	12.623	35.655	178.361
	15.1	79	2	120	90.655	2.459	314.754
4	10.8	104.8	1	100	120.262	1.229	262.295
	13.2	65.67	3	142	75.359	3.688	372.459
5	17	36	2	165	41.311	2.459	432.787
	-	-	-	-	-	-	-
6	9.3	297.78	1	128	341.715	1.229	335.738
	14.95	114	2	89	130.819	2.459	233.443
7	19.27	25	2	32	28.689	1.229	83.934
	21.01	99	3	37	113.606	3.688	97.049
8	12.2	1,201	1	148	1,378.196	1.229	388.197
	20.73	426	3	24	488.852	3.688	62.951

9	17.13	440	1	55	504.918	1.229	144.262
	21.02	560	2	27	642.623	2.459	70.819
10	11.73	5,983	1	472	6,865.738	1.229	1,238.033
	20	11	28	100	12.623	34.426	262.295
11	15.94	12,635	5	603	14,499.180	6.148	1,581.639
	18.39	1,259	13	352	1,444.754	15.983	923.279
12	17	840	3	103	963.934	3.688	270.164
	20.1	10	11.5	95	11.475	14.139	249.180
13	20.89	1,610	7	76	1,847.541	8.606	199.244
	18.52	871	6	110	999.508	7.377	288.525
14	20.1	11	12.6	98	12.623	15.491	257.049
	18.02	22	1	66	25.245	1.229	173.115
15	15.95	7,472	1	385	8,574.426	1.229	1,009.836
	13.4	8,481	1	324	10,145.410	1.229	849.836
16	18.6	11,300	11	386	12,967.213	450.820	1,012.459
	-	-	-	-	-	-	-
17	13.93	7,759	4	347	8,905.770	4.918	910.164
	14.28	10,817	5	428	12,412.951	6.148	1,122.623
18	15.029	9,660	7	366	11,085.246	8.607	960
	13	483	2	96	554.262	2.459	251.803
19	12.031	10,797	7	407	12,390	8.606	1,067.541
	11.39	12,454	6	460	14,291.475	7.377	1,206.557
20	14.15	12,762	14	467	14,644.918	17.213	1,224.918
	15.1	90	5	300	103.279	6.148	786.885
21	14.1	1,916	9	332	2,198.688	11.066	870.820
	14.03	9,225	12	325	10,586.065	14.754	852.459
22	20.86	645	8	109	740.164	9.836	285.902
	11.63	5,983	6	472	6,865.738	7.377	1,238.033
23	20.79	3,612	5	43	4,144.918	6.148	112.787
	21	60	3	34	68.852	3.688	89.180
24	16.87	2,008	9	353	2,304.262	11.066	925.902
	-	-	-	-	-	-	-
25	14.33	4,809	2	530	5,518.525	2.459	1,390.164
	19.23	2,596	1	320	2,979.016	1.229	839.344
26	20.2	11	3	100	12.622	3.688	262.295
	16.3	50.2	1	98	57.607	1.229	257.049
27	13.8	1,123	4	436	1,288.689	4.918	1,143.607
	14.3	368	3	78	422.295	3.688	204.590
28	16.3	1,115	3	39	1,279.508	3.688	102.295
	-	-	-	-	-	-	-
29	13	498.7	7	299.9	572.279	8.607	786.622
	12.7	159.8	5	174.9	183.377	6.148	458.754
30	20.54	12,229	4	66	14,033.278	4.198	173.115
	11.45	5,248	3	564	6,022.295	3.688	1,479.344

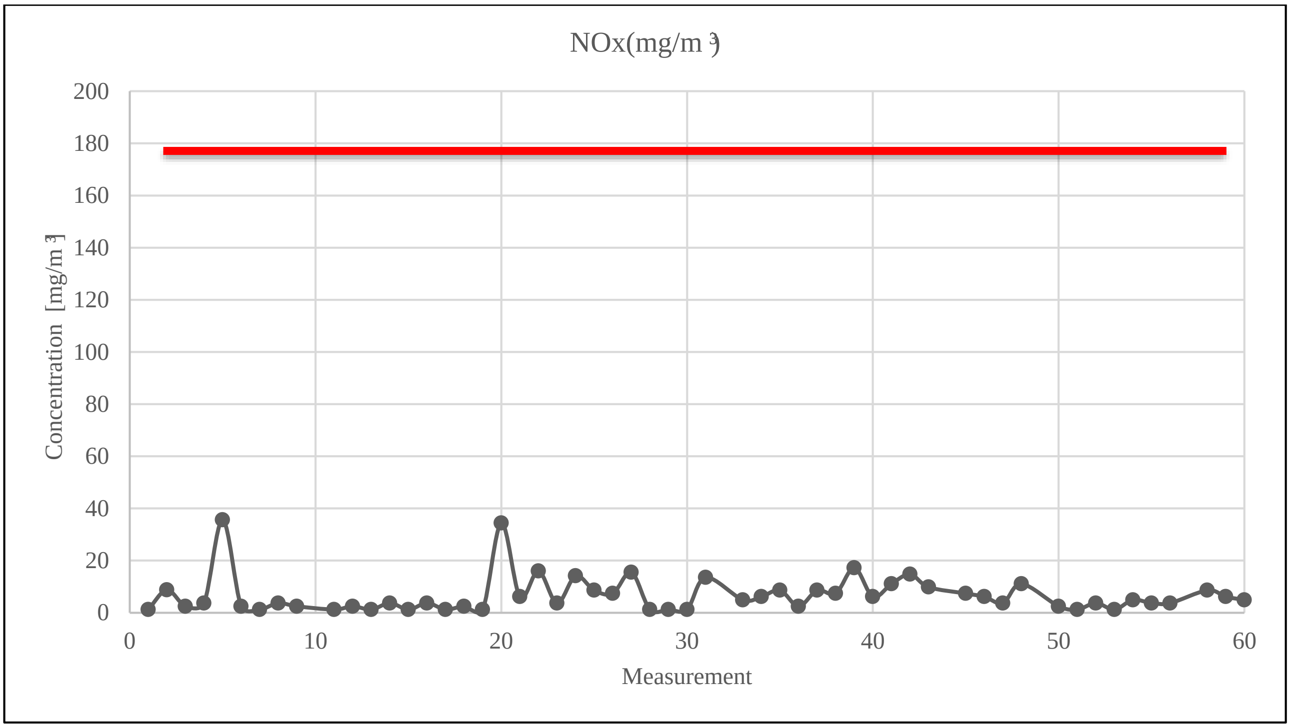

Fig. 1 NO_x monitoring.

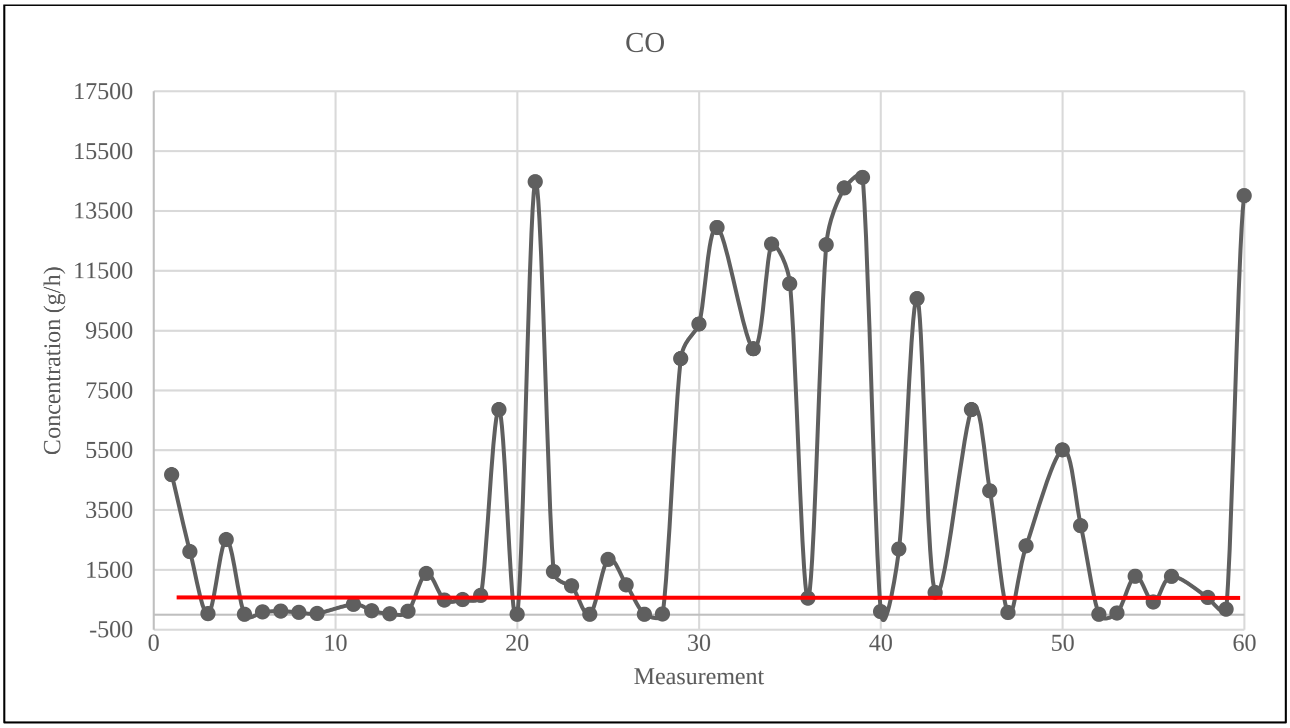

Fig. 2 CO monitoring.

Some of the CO values obtained were at the permissible limit, while in many cases, they exceeded it, indicating incomplete combustion. It is worth noting that the crematorium is equipped with two combustion chambers: the first for the cremation of the body and the second for the complete oxidation of combustion gases (Table 2).

The data indicate higher emissions of CO, followed by SO_2, and to a lesser extent NO_x. There is a possibility that CO could react with oxygen and NO_x to produce ozone (near the Earth's surface), which can cause burns in humans and damage native flora and fauna [6].

To assess the contribution of crematorium emissions to air quality in the town of Tlalmanalco, State of Mexico, a box-and-whisker analysis was conducted using air quality data from a monitoring station of the RAMA for the years 2019 and 2022 (Fig. 3).

There is a significant difference between the years 2019 and 2022. Using the 2019 concentrations as a baseline, CO levels increased 15-fold, NO_x increased 1.3-fold, and SO_2 increased 5.14-fold. This occurred despite Tlalmanalco being the least populated municipality in the State of Mexico, with 49,196 inhabitants [8].

Using the average concentration data and the volumetric emission flow at the chimney, the average emission rates of the gases were calculated as follows: 84.03 g NO_x/h, 46,194.4 g CO/h, and 7,050.9 g SO_2/h.

Table 2 Statistical analysis of sampling data.

Combustion gases	CO (mg/m^3)	NO_x (mg/m^3)	SO_2 (mg/m^3)
Maximum value	14,644.958	35.655	1,581.639
Minimum value	11.475	1.229	62.951
Range	1,463.483	34.426	1,518.688
Average value	3,653.266	6.645	557.623
Standard deviation	4,184.516	6.997	442.255

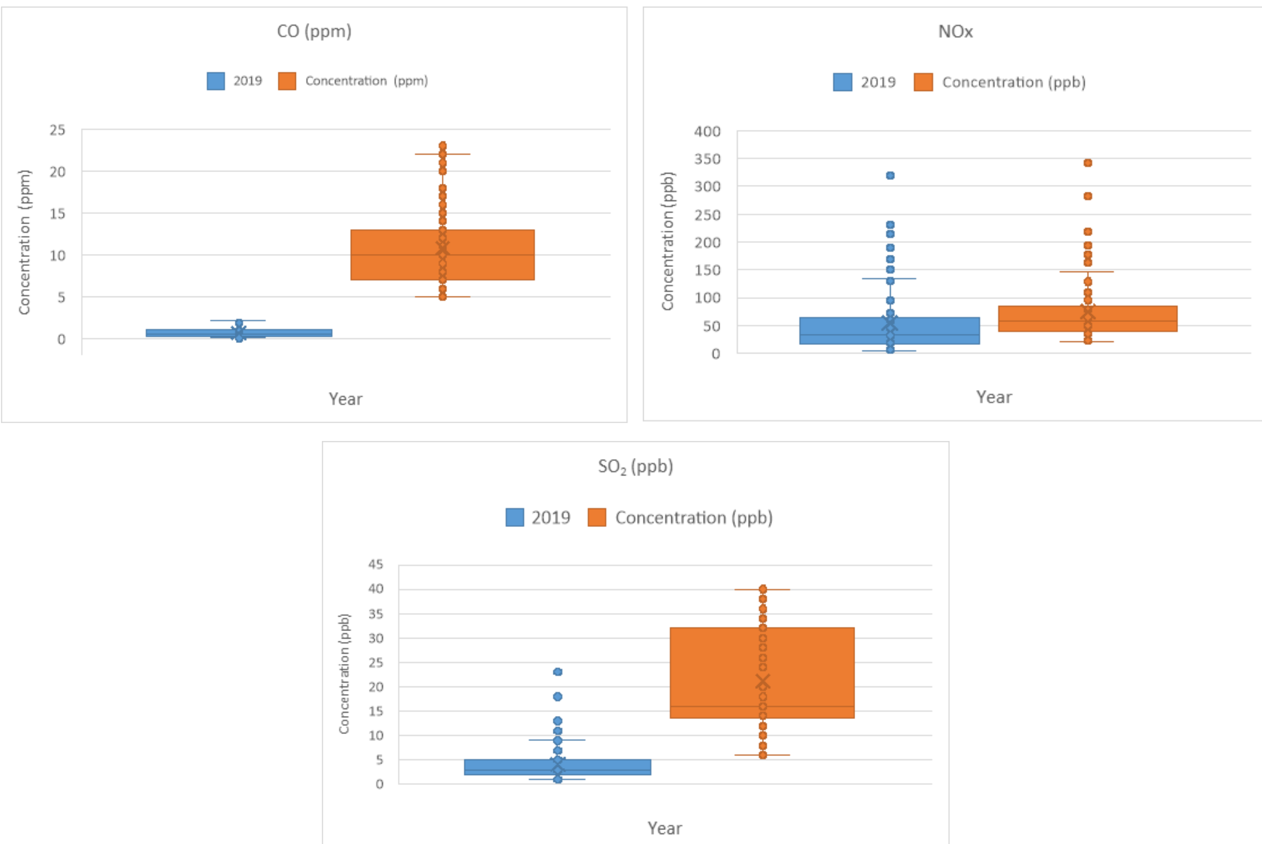

Fig. 3 Box-and-whisker plot for CO, NO_x, and SO_2 concentrations.

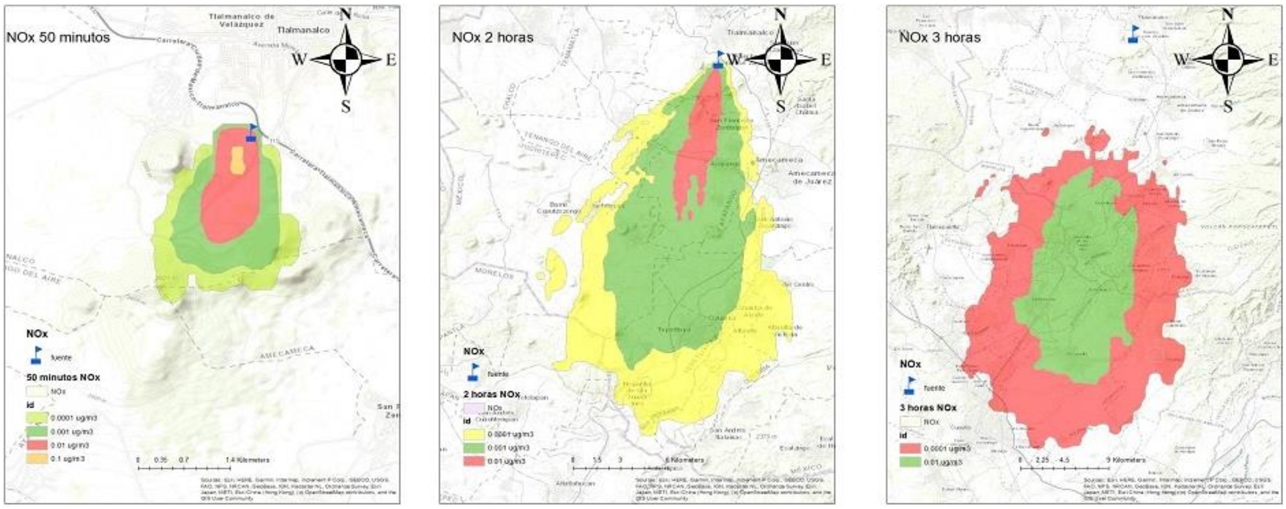

Fig. 4 NO_x dispersion model for different time periods.

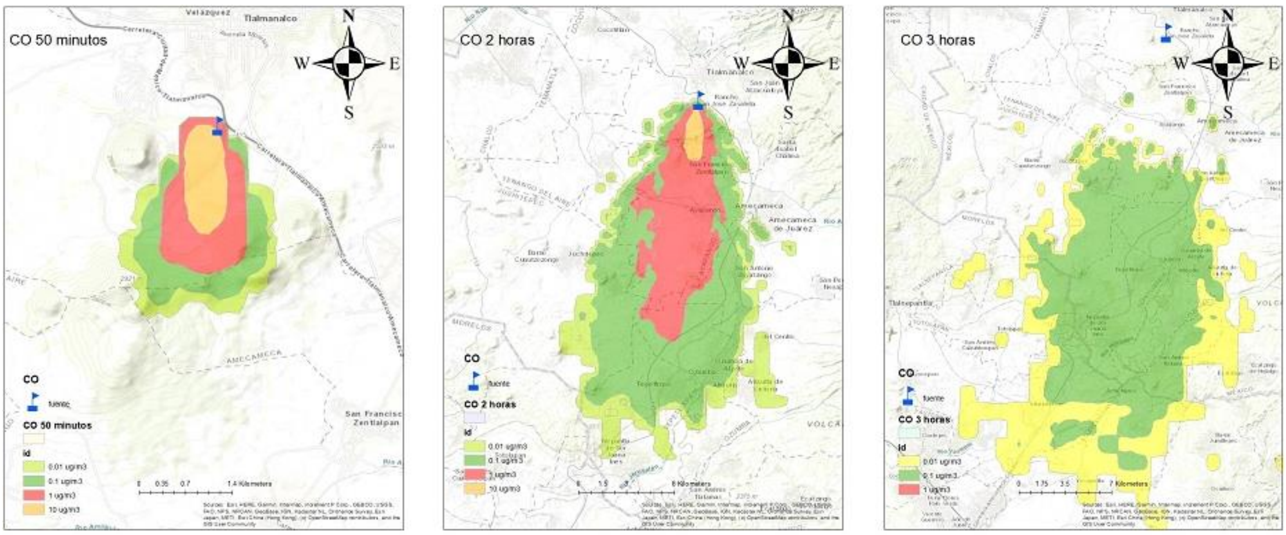

Fig. 5 CO dispersion model for different time periods.

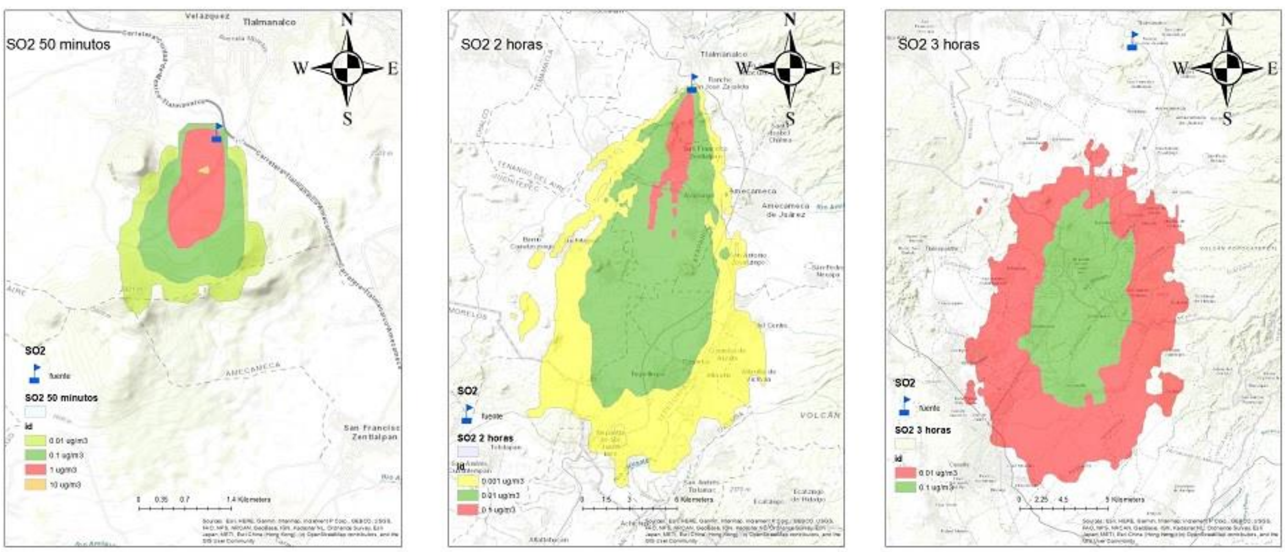

Fig. 6 SO_2 dispersion model for different time periods.

Table 3 Comparison of results of the dispersion model.

Pollutant	Standard	Concentration Max. limit in 1 h (μg/m^3)	Concentration Result of the dispersion model (μg/m^3)
CO	NOM-021-SSA1-2021	30,000	10
NO_x	NOM-022-SSA1-2019	196.5	0.1
SO_2	NOM-023-SSA1-2021	200	1

The HYSPLIT dispersion model was used to analyze the trajectory of these gases over periods of 50 min, 2 h, and 3 h, corresponding to the approximate duration of the cremation service (2 h). The model requires the average emission rates, site meteorological data (collected from RAMA), and the following assumptions:

- The chemical species do not undergo any reactions; they remain unchanged from emission to dispersion.
- The maximum mixing height is 1,300 m.
- Deposition processes are not considered.
- The chimney height is 6 m.
- The density of the gases is not considered.

The results of the HYSPLIT dispersion model are shown in Fig. 4 for NO_x, Fig. 5 for CO, and Fig. 6 for SO_2.

From the dispersion model images, it can be observed that the pollutants disperse towards the southwest. After 50 min, the maximum concentration of CO is 10 μg/m³, NO_x reach 0.1 μg/m³, and SO_2 is at 1 μg/m³. Beyond this point, the concentration of all pollutants decreases.

Using this data, a comparison was made with the limits established by the Ministry of Health under the standards NOM-021-SSA1-2021, NOM-022-SSA1-2019, and NOM-023-SSA1-2021, as these gases are emitted from a fixed source (Table 3).

Therefore, it is concluded that the operation of the crematorium does not affect the air quality in the Tlalmanalco Municipality, State of Mexico.

4. Conclusions

CO emissions exceed the maximum values allowed by fixed-source regulations issued by the Ministry of Environment and Natural Resources, highlighting the need for monitoring and adjustments to prevent incomplete combustion.

A comparison of pollutant gas data between 2019 and 2022 confirmed an increase attributable not only to cremation activities but also to other sources of pollution in the Municipality of Tlalmanalco.

The cremation process involves several variables, including the weight of the body, duration, temperature, and air injection, as each case is unique. However, variables such as duration and air intake can be optimized to improve the efficiency of the process.

The dispersion of pollutants within one hour, as indicated by the dispersion model, remains within the limits established by the air quality regulations of the Ministry of Health, ensuring compliance with air quality standards.

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